POLARIZATION DIVERSITY RECEIVER WITH PLANAR WAVEGUIDE AND POLARIZING BEAM SPLITTER

FIELD OF THE INVENTION

The invention relates generally to the field of optical measurements and measuring systems, and more particularly to a system for optical heterodyne detection of an optical signal.

BACKGROUND OF THE INVENTION

Dense wavelength division multiplexing (DWDM) requires optical spectrum analyzers (OSAs) that have higher spectral resolution than is typically available with current OSAs. For example, grating based OSAs and autocorrelation based OSAs encounter mechanical constraints, such as constraints on beam size and the scanning of optical path lengths, which limit the degree of resolution that can be obtained. As an alternative to grating based and autocorrelation based OSAs, optical heterodyne detection systems can be utilized to monitor DWDM systems.

Optical heterodyne detection systems are utilized for optical spectrum analysis of an input optical signal. Fig. 1 is a depiction of a prior art heterodyne-based detection system that includes a fiber coupler 110 that combines an input signal 102 from an input fiber 104 with a swept local oscillator signal 106 from a local oscillator source 105 via a local oscillator fiber 108. The combined optical signal travels on an output fiber 118 and is detected by a receiver 112. Square law detection results in mixing of the two combined waves and produces a heterodyne beat signal at a frequency that is equal to the frequency difference between the combined waves. The receiver converts optical radiation from the combined optical signal into an electrical signal. The electrical signal is processed by a signal processor 116 to determine a characteristic of the input signal, such as frequency, wavelength, or amplitude. In order to prevent fading of the heterodyne beat signal, it is important that the

polarization states of the input signal and the swept local oscillator signal are matched. One technique for matching the polarization states of the input signal and the swept local oscillator signal involves adjusting the polarization state of the swept local oscillator signal with a polarization controller 120 to track changes in the polarization state of the input signal. A disadvantage of the polarization matching technique is that a polarization tracking system is required.

A polarization diversity receiver can be incorporated into a heterodyne-based OSA to provide polarization independent signal detection. Fig. 2 is a depiction of a heterodyne-based OSA that incorporates a polarization diversity receiver. Throughout the specification, similar elements are identified by similar reference numerals. The heterodyne-based OSA includes a polarization controller 220 on the local oscillator fiber 208, a fiber coupler 210, a polarizing beam splitter 224, two receivers 212 and 214, and a processor 216. The fiber coupler is optically connected to the polarizing beam splitter by the output fiber. The polarizing beam splitter splits the combined optical signal into two orthogonally polarized beams that are separately detected by the respective receivers. The power of the local oscillator signal 206 is split equally between the receivers 212 and 214 by adjusting the polarization state of the local oscillator signal. The orthogonally polarized beams that are detected by the two receivers include an intensity noise component and the heterodyne beat signal, as is known in the field of optical heterodyne detection. The strength of the heterodyne beat signal is recovered by squaring and adding the individual signals from both receivers.

Although the heterodyne detection systems of Figs. 1 and 2 work well, they both utilize fiber couplers which exhibit some undesirable optical characteristics. Specifically, fiber couplers tend to introduce unstable birefringence and their output coupling ratio can vary with the wavelength or polarization state of the incoming optical signals.

As an alternative to fiber couplers, other optical heterodyne detection systems utilize polarizing beam splitters to combine the input signal with the local oscillator signal. Using a polarizing beam splitter to combine an input signal with a local oscillator signal requires precise alignment between the input signal and the local oscillator signal within the polarizing beam splitter. Specifically, the input fiber and

local oscillator fiber must be precisely secured at outer faces of the polarizing beam splitter. The precise alignment required to couple two optical signals with a polarizing beam splitter makes these systems expensive to produce.

In view of the prior art limitations, what is needed is an optical heterodyne detection system that provides polarization independence, intensity noise suppression, and is economical to produce.

SUMMARY OF THE INVENTION

A system for optical detection includes a planar waveguide optical coupler that is directly adjacent to a polarizing beam splitter. The planar waveguide optical coupler combines an input signal with a local oscillator signal and the polarizing beam splitter divides the combined optical signal into orthogonally polarized beams. The orthogonally polarized beams are detected by first and second optical detectors. The planar waveguide optical coupler is directly adjacent to the polarizing beam splitter when no optical fibers or lenses are needed to transfer optical signals from the planar waveguide optical coupler to the polarizing beam splitter. In one embodiment, the planar waveguide optical coupler is in contact with the polarizing beam splitter, in another embodiment, the planar waveguide optical coupler is attached to the polarizing beam splitter, and in another embodiment, the planar waveguide optical coupler and the polarizing beam splitter are attached to opposite sides of a polarization rotator. Locating the planar waveguide directly adjacent to the polarizing beam splitter reduces birefringence and alignment problems associated with prior art systems. Larger alignment tolerances enable the optical detection system to be more efficiently fabricated.

An embodiment of a system for optical heterodyne detection includes a planar waveguide optical coupler, a polarizing beam splitter, and first and second optical detectors. The planar waveguide optical coupler combines an input signal and a local oscillator signal into a combined optical signal, with the planar waveguide optical coupler having a first output for outputting a first beam of the combined optical signal. The polarizing beam splitter is directly adjacent to the first output of the

planar waveguide optical coupler and splits a beam based on its state of polarization. The polarizing beam splitter is optically connected to the first output of the planar waveguide optical coupler to receive the first beam. The polarizing beam splitter outputs two polarized portions of the first beam. The first and second optical detectors are optically connected to detect a different one of the two polarized portions of the first beam. The first and second optical detectors generate electrical signals in response to respective ones of the two polarized portions of the first beam.

In an embodiment, the polarizing beam splitter is in contact with the first output of the planar waveguide optical coupler.

In another embodiment, the polarizing beam splitter is attached to the planar waveguide optical coupler.

In an embodiment, the polarizing beam splitter is a walk-off crystal.

In an embodiment of the system, the planar waveguide optical coupler includes a second output for outputting a second beam of the combined optical signal and the polarizing beam splitter is optically connected to the second output of the planar waveguide optical coupler to receive the second beam. The polarizing beam splitter outputs two polarized portions of the second beam. The system also includes third and fourth optical detectors that are optically connected to detect a different one of the two polarized portions of the second beam, the third and fourth optical detectors generating electrical signals in response to respective ones of the two polarized portions of the second beam.

In another embodiment, the system includes a processor for receiving the electrical signals from the optical detectors and for generating an output signal that is indicative of an optical parameter of the input signal, wherein the processor monitors a heterodyne beat signal that is a component of the combined optical signal.

In another embodiment, the system includes a polarization rotator located between the planar waveguide optical coupler and the polarizing beam splitter.

In the optical system described above, if the local oscillator signal is swept across a range of frequencies, the optical detection system can serve as an optical spectrum analyzer. A system for optical spectrum analysis includes a planar waveguide optical coupler, a polarizing beam splitter, and first and second optical detectors. The planar waveguide optical coupler combines an input signal and a

swept local oscillator signal into a combined optical signal, the planar waveguide optical coupler having a first output for outputting a first beam of the combined optical signal. The polarizing beam splitter is directly adjacent to the first output of the planar waveguide optical coupler and splits a beam based on its state of polarization. The polarizing beam splitter is optically connected to the first output of the planar waveguide optical coupler to receive the first beam. The polarizing beam splitter outputs two polarized portions of the first beam. The first and second optical detectors are optically connected to detect a different one of the two polarized portions of the first beam. The first and second optical detectors generate electrical signals in response to respective ones of the two polarized portions of the first beam.

In an embodiment of the optical spectrum analyzer, the polarizing beam splitter is in contact with the first output of the planar waveguide optical coupler.

In another embodiment of the optical spectrum analyzer, the polarizing beam splitter is attached to the planar waveguide optical coupler. In an embodiment, the polarizing beam splitter is bonded to the planar waveguide optical coupler.

In an embodiment of the optical spectrum analyzer, the polarizing beam splitter is a walk-off crystal.

In an embodiment of the optical spectrum analyzer, the planar waveguide optical coupler includes a second output for outputting a second beam of the combined optical signal and the polarizing beam splitter is optically connected to the second output of the planar waveguide optical coupler to receive the second beam, the polarizing beam splitter outputting two polarized portions of the second beam. The system also includes third and fourth optical detectors that are optically connected to detect a different one of the two polarized portions of the second beam. The third and fourth optical detectors generating electrical signals in response to respective ones of the two polarized portions of the second beam. An embodiment further includes a processor for receiving the electrical signals from the optical detectors and for generating an output signal that is indicative of an optical parameter of the input signal, wherein the processor monitors a heterodyne beat signal that is a component of the combined optical signal. Another embodiment includes a fiber holder that aligns first, second, third, and fourth fibers to the output points of the polarized portions of the first and second beams.

In an embodiment of the optical spectrum analyzer, a lens is located between the polarizing beam splitter and the first and second optical detectors for directing the two polarized portions of the first beam into first and second optical fibers that are optically connected to the first and second optical detectors.

In an embodiment of the optical spectrum analyzer, a tunable laser is optically connected to the planar waveguide optical coupler for generating the swept local oscillator signal.

In an embodiment a polarization rotator is located between the planar waveguide optical coupler and the polarizing beam splitter.

In an embodiment of the optical spectrum analyzer, an attenuator is connected to attenuate the input signal before the input signal reaches the planar waveguide optical coupler.

In an embodiment of the optical spectrum analyzer, a tunable optical filter connected to attenuate the input signal before the input signal reaches the planar waveguide optical coupler.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a depiction of an optical heterodyne detection system in accordance with the prior art.

Fig. 2 is a depiction of an optical heterodyne detection system that includes a polarization diversity receiver, in accordance with the prior art.

Fig. 3 is a depiction of a heterodyne-based OSA with a planar waveguide optical coupler and an adjacent polarizing beam splitter in accordance with an embodiment of the invention.

Fig. 4 is a perspective view of the planar waveguide optical coupler and the adjacent polarizing beam splitter shown in Fig. 3.

Fig. 5 is a front view of a quadrant receiver that is used to detect the output optical signals from the system shown in Figs. 3 and 4.

Fig. 6 is a graphical depiction of the signal processing that is performed on the electrical signals that are generated from the quadrant receiver of Fig. 5.

Fig. 7 is a depiction of a heterodyne-based OSA with a planar waveguide optical coupler, a polarizing beam splitter, and a polarization rotator located between the planar waveguide optical coupler and the polarizing beam splitter in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

An embodiment of the invention involves an optical spectrum analyzer in which a planar waveguide optical coupler is directly adjacent to a polarizing beam splitter. The planar waveguide optical coupler combines an input signal with a swept local oscillator signal and the polarizing beam splitter divides the combined optical signal into orthogonally polarized beams.

Fig. 3 is a depiction of a heterodyne-based optical spectrum analyzer in which a planar waveguide optical coupler is directly adjacent to a polarizing beam splitter. The optical spectrum analyzer includes a signal fiber 304, a local oscillator source 305, a local oscillator fiber 308, a planar waveguide optical coupler 310, a polarizing beam splitter 324, a lens 326, a fiber holder 328, a heterodyne receiver 312, and a processor 316. It should be noted that throughout the description, similar reference numerals are utilized to identify similar elements. Additionally, the term "optical" is not limited to the visible spectrum but includes other light spectrums, such as the infrared spectrum.

The signal fiber 304 carries an input signal that is to be detected by the system. In an embodiment, the signal fiber is a single mode optical fiber as is known in the field, although other optical waveguides may be utilized. In addition, although waveguides are described, optical signals may be input into the system, or transmitted within the system, in free space.

The input signal 302 includes optical signals that are generated from conventional devices as is known in the field of optical communications systems. For example, the input signal may be generated from a single laser or multiple lasers and may consist of a single wavelength or multiple wavelengths as is known in the field of wavelength division multiplexing. In addition to the wavelength characteristic, the input signal also has a polarization state that can be defined at any point in time. Although the polarization state of the input signal can be defined at any point in time, the polarization state of the input signal may be changing during signal transmission.

In an embodiment, the input signal 302 has unknown optical characteristics that are measured by the optical spectrum analyzer. The input signal may alternatively be an optical signal that is input with known optical characteristics, in which case the optical spectrum analyzer can be utilized for optical network analysis. In an embodiment, a known input signal may be a delayed portion of the local oscillator signal. When the optical spectrum analyzer is utilized for optical network or component analysis, the characteristics of a network or a single component can be determined by inputting a known input signal into the network or the single component and then measuring the response to the known signal.

The local oscillator source 305 generates a local oscillator signal. In an embodiment, the local oscillator source is a highly coherent wideband tunable laser that is tunable over a wavelength range of one nanometer or greater. During optical spectrum analysis, the local oscillator source generates a highly coherent local oscillator signal that is swept across a range of frequencies, or wavelengths, in order to detect the input signal over the range of frequencies or wavelengths. The local oscillator fiber 308 is an optical fiber, such as polarization maintaining optical fiber that carries the local oscillator signal 306 to the planar waveguide optical coupler 310. Other optical waveguides, or free space transmission, may be utilized in place of polarization maintaining optical fiber. Optical detection can alternatively be achieved without sweeping the local oscillator signal.

The planar waveguide coupler 310 combines the input signal 302 and the swept local oscillator signal 306 into a combined optical signal. Two portions of the combined optical signal are output from the planar waveguide optical coupler at an output face 332. Although the planar waveguide optical coupler shown in Fig. 3 has

two outputs, a planar waveguide optical coupler with one or more outputs can be utilized to transmit a portion of the combined optical signal to the heterodyne receiver 312.

The polarizing beam splitter 324 is directly adjacent to the output face 332 of the planar waveguide optical coupler 310. The polarizing beam splitter receives the two beams of the combined optical signal directly from the planar waveguide optical coupler. Herein, two optical elements are "directly adjacent" when no optical elements, e.g., fibers, lenses, or mirrors, are needed to transfer optical signals from one element to the other. In an embodiment, the planar waveguide optical coupler and polarizing beam splitter are directly adjacent when no optical fibers or lenses are needed to make the optical connection. In an embodiment, the planar waveguide optical coupler and polarizing beam splitter are directly adjacent when an input face 334 of the polarizing beam splitter is in contact with the output face of the planar waveguide optical coupler 310. In another embodiment, the planar waveguide optical coupler and polarizing beam splitter are directly adjacent when the polarizing beam splitter is attached to the planar waveguide optical coupler. In an embodiment, attaching the planar waveguide optical coupler to the polarizing beam splitter involves adjusting the orientation of the polarizing beam splitter to generate four evenly spaced output beams and then bonding the two components together with a bonding material such as epoxy. The polarizing beam splitter 324 separates an incoming optical beam into two polarized beams. The polarizing beam splitter may include, for example, a birefringent crystal that provides polarization walk-off, such as a rutile walk-off crystal. As will be described below, the polarizing beam splitter separates each of the combined optical signal beams into two beams having different polarization states. Preferably, the polarizing beam splitter separates each of the incoming beams into two linearly polarized components that have orthogonal directions of polarization. Although the polarizing beam splitter is described as a single device, the polarizing beam splitter may include multiple beam splitters in configurations that accomplish the task of splitting an incoming beam based on beam polarization.

Because the planar waveguide optical coupler 310 is directly adjacent to the polarizing beam splitter 324, the birefringence problems of fiber couplers and the alignment problems of polarizing beam splitter are avoided. Additionally, the large

alignment tolerances allowed by placing the polarizing beam splitter directly adjacent to the planar waveguide optical coupler enables the use of cost effective fabrication processes.

Fig. 4 is a perspective view of the planar waveguide optical coupler 410 and the polarizing beam splitter 424 that are shown in Fig. 3. Fig. 4 shows how the two beams of the combined optical signal are split into two differently polarized beams. As shown in Fig. 4, the bottom beams 440 follow an "ordinary" path and are referred to as the ordinary beams. The top beams 442 walks off in an "extraordinary" path and are referred to as the extraordinary beams.

In an embodiment, the polarization of the local oscillator signal is controlled such that the power of the local oscillator signal is distributed approximately evenly among the four photodetectors of the optical receiver 312.

Referring back to Fig. 3, four beams are output from the polarizing beam splitter 324. In the embodiment of Fig. 3, the four beams are output to a lens, such as a gradient index (GRIN) lens, which refract light due to variations of their index of refraction. The lens focuses the four beams and directs each one of the four beams into a separate one of four optical fibers 336 that are held in place with a two-by-two fiber holder 328. The four optical fibers guide the four separate output beams to the optical receiver. In the embodiment of Fig. 3, the two-by-two fiber holder is sized such that it aligns the fibers with the exit points of the four beams from the polarizing beam splitter 324. In an alternative embodiment, the length of the polarizing beam splitter is chosen such that the spacing between the four output beams matches the spacing of the fibers within the fiber holder.

The optical receiver 312 includes four independent photodetectors 344, 346, 348, and 350 that are aligned to separately detect the four polarized beams that are output from the polarizing beam splitter 324. In an embodiment, the four independent photodetectors are coupled or "pigtailed" to the four optical fibers 336. The four independent photodetectors can be combined into a single quadrant receiver for packaging reasons, however, the four independent photodetectors could alternatively be, for example, four photodetectors that are physically separate. Although not shown, the receiver may include signal amplifiers and filters, as is known in the field.

Fig. 5 is a front view of an embodiment of a quadrant receiver that includes four photodetectors 544, 546, 548, 550. As shown in Fig. 5, the two left photodetectors 544 and 546 of the receiver are partially identified by "1," which corresponds to the beam (beam 1) that is one of the two beams that are output from planar waveguide optical coupler 310. The two right photodetectors 548 and 550 are partially identified by the number "2," which corresponds to the beam (beam 2) that is the other one of the two beams that are output from the optical coupler. The two bottom photodetectors 544 and 548 are partially identified by the letter "o," which corresponds to the ordinary beams exiting from the polarizing beam splitter. The two top photodetectors 546 and 550 are partially identified by the letter "e," which corresponds to the extraordinary beams exiting from the polarizing beam splitter. Under this convention, the four beams and the respective photodetectors are identified as "1o," "1e," "2o," and "2e."

Referring back to Fig. 3, the electrical signals generated by each of the four photodetectors in the optical receiver 312 are individually provided to the processor 316. The four connections between the optical receiver and the processor are depicted in Fig. 3 by four lines 352.

The processor 316 includes a multifunction processor that receives the electrical signals from the heterodyne receiver 312 and isolates the heterodyne beat signal from the heterodyne receiver to generate an output signal that is indicative of an optical parameter, such as optical frequency, wavelength, or amplitude, of the input signal 302. The processor may include either or both analog signal processing circuitry and digital signal processing circuitry, as is known in the field of electrical signal processing. In an embodiment, an analog signal from the receiver is converted into a digital signal and the digital signal is subsequently processed to generate an output signal.

Operation of the system described with reference to Figs. 3 – 5 involves combining an input signal and a swept local oscillator signal in the planar waveguide optical coupler 310. The combined optical signal is then split into two beams that each include a portion of the input signal and the local oscillator signal. The two beams exit the planar waveguide optical coupler and immediately enter the adjacent polarizing beam splitter 324. Each of the two beams containing the combined optical

signal is then split by the polarizing beam splitter into two polarized beams having orthogonal polarization states. The four polarized beams exit the polarizing beam splitter and enter the lens 326. The lens focuses the four polarized beams and directs the beams into the beam-specific fibers 336. The four beam-specific fibers direct the four polarized beams to the optical receiver 312 and each of the four photodetectors within the receiver generates electrical signals in proportion to the intensity of the optical beams that are detected. The electrical signals generated by the four photodetectors are then received by the processor 316 and processed in a manner that isolates and maximizes the heterodyne term of the combined optical signal. Processing of the electrical signals involves providing intensity noise suppression and polarization diversity. As is described below, the system may require an initial calibration operation in order to provide accurate results.

Fig. 6 is an example graphical depiction of how the electrical signals generated from the four photodetectors 644, 646, 648, and 650 of a quadrant receiver are processed to achieve intensity noise suppression and polarization diversity. As described above, the signal processing preferably involves digital signal processing although this is not critical. Initially, signal subtractions are performed between the "1o" signal and the "2o" signal, and between the "1e" signal and the "2e" signal. The subtraction functions are represented by subtraction units 654 and 656, respectively. The subtraction functions are performed to provide intensity noise suppression by canceling out the intensity noise components of the optical signals that are received by each photodetector. The subtraction functions cancel out the intensity noise because the intensity noise is common between each signal. That is, the amplitudes of the "1e" and "2e" signals fluctuate in a synchronized manner and by the same percentage relative to each other, and the "1o" and "2o" signals fluctuate in a synchronized manner and by the same percentage relative to each other.

Additional signal processing is implemented on the subtracted signals to provide polarization diversity. Because the combined optical signal beams are split into orthogonal states of polarization, one of the beams is proportional to $\cos\theta$ and the other beam is proportional to $\sin\theta$, where θ is the angle of polarization of the input signal with respect to the ordinary axis of the polarizer. In the example of Fig. 6, the electrical signals generated from the ordinary beam portions include a $\cos\theta$ term and

the electrical signals generated from the extraordinary beam portions include a sinθ term. The cosθ term is squared, as represented by squaring unit 658, and the sinθ term is squared, as represented by squaring unit 660. The squaring units generate output signals that are proportional to the square of the input signals. The output signals from the squaring units are each connected to low pass filtering units 664 and 668. The low pass filtering units provide low pass filtering on the squared output signals. The output signals from the low pass filtering units are each connected to an input terminal of an adder unit, designated 670, which produces a readout signal that is proportional to the sum of the signals from the low pass filtering units. Squaring the cosθ term and the sinθ term, low pass filtering the terms, and then adding the squared and filtered cosθ term to the squared and filtered sinθ term provides a result that is independent of the angle of polarization (θ) of the input signal and therefore polarization diverse. It should be understood that in a digital system the subtracting, squaring, low pass filtering, and adding units may be incorporated into a multi-function processor.

The combination of the planar waveguide optical coupler 310, the polarizing beam splitter 324, the optical receiver 312, the processor 316, and the signal processing units 654, 656, 658, 660, 664, 668, and 670 creates a system that is insensitive to the polarization state of the input signal and that suppresses the intensity noise of the split beams that are detected by the four photodetectors. In an embodiment, a switch 364 is utilized to selectively block transmission of the input signal in order to calibrate the system. For example, while the input signal is switched off, the coupling coefficient of the planar waveguide optical coupler 310 can be determined as a function of wavelength by sweeping the local oscillator signal across a range of wavelengths. In addition, the responsivity of the photodetectors can be determined as a function of wavelength by sweeping the local oscillator signal while the input signal is switched off.

Further, the distribution of the local oscillator signal onto the photodetectors can be determined as a function of wavelength by sweeping the local oscillator signal while the input signal is switched off. It is preferable that the local oscillator signal is approximately evenly distributed among the four photodetectors of the receiver to

achieve good polarization diversity. If the local oscillator signal is not evenly distributed among the four photodetectors, then the power distribution of the local oscillator signal may be adjusted utilizing the polarization controller 320. In an embodiment, the polarization controller may include a half-wave plate.

Fig. 7 depicts an alternative embodiment of the heterodyne-based OSA described above that includes a polarization rotator 772 located between the planar waveguide optical coupler 710 and the polarizing beam splitter 724. In the embodiment of Fig. 7, the planar waveguide optical coupler and polarizing beam splitter are maintained directly adjacent to each other even though they are separated by the polarization rotator. In an embodiment, the polarization rotator is a quarter wave plate. The polarization rotator is added to adjust the power distribution of the local oscillator signal

The heterodyne-based OSA of Fig. 7 also includes an optional attenuator and an optional optical filter. The optional attenuator 774 is integrated into the input fiber 704 in order to attenuate the input signal 702. Attenuating the input signal reduces the intensity noise that is generated by the input signal during detection by the heterodyne receiver 712. The particular type of attenuator is not critical and therefore various types of attenuators, as are known in the field of optical attenuation, may be utilized. Preferably, the attenuator is adjustable such that the level of attenuation can be varied as needed to control the intensity of the input signal that is passed to the planar waveguide optical coupler 710. In an embodiment, the attenuator can be adjusted to completely block transmission of the input signal. Completely blocking transmission of the input signal can be useful during system calibration.

The optional optical filter 776 is a tunable bandpass filter that is tuned to track the swept local oscillator signal 706. That is, the optical filter is tuned so that the optical filter has the highest optical transmission over a frequency band that corresponds to the frequency of the swept local oscillator signal. The optical filter may be tuned to track the swept local oscillator signal utilizing known frequency tracking techniques. In an embodiment, the center of the filter passband is tuned to the frequency of the swept local oscillator signal. In another embodiment, the center of the filter passband is tuned slightly off the local oscillator frequency in order to generate the heterodyne signal at a higher frequency, for example, when image

rejection is important. Tunable optical filters are well known in the field of optical communications and can be implemented utilizing components such as diffraction gratings, dielectric interference filters, periodic Bragg devices, such as tunable fiber Bragg gratings, Fabry-Perot interferometers, and other known interferometers.

Although specific embodiments of the invention have been described and illustrated, the invention is not limited to the specific forms and arrangements of parts so described and illustrated. The invention is limited only by the claims.